OUTLINE OF THE OBSERVATIONS OF CLOUDS AND PRECIPITATION IN ARCTIC CANADA (CONTRIBUTION TO POLEX-NORTH)

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Abstract: Experiments in the Arctic (POLEX-North) were carried out in Arctic Canada during the period from November 1979 to January 1980. The main object of the experiments was to study the mechanism of variation of heat sink in the Arctic area, through observations of clouds and precipitation. The main observations were as follows:

(a) Observation of fine structure of precipitating clouds by 8.6 mm vertically pointing radar;

(b) Observation of distribution and movement of precipitating clouds by 3.2 cm PPI radar;

(c) Observation of types and numbers of snow crystals on the ground by the use of the plastic replica method, microscopes and automatic recorder;

(d) Sampling of new snow and deposited snow for the measurement of $\delta^{18}O$ and trace elements.

This paper contains only summaries of the papers in the "Observations of Clouds and Precipitation in the Arctic Canada (ed. by HIGUCHI, TAKEDA and KIKUCHI, Organizing Committee for POLEX, Tokyo, 189 p., 1981)".

1. Introduction

POLEX and polar sub-programme activities of Japan can be divided into three parts; first, experiments in the Antarctic (POLEX-South), second, experiments in the Arctic (POLEX-North), and third, modelling studies. Experiments in the Antarctic have been progress since 1978, to carry out a radiation programme, planetary boundary layer observations, and local circulation observations. Modelling studies have also been going on since 1979, to study effects of radiation, clouds, low level inversion and ice boundary in the Antarctic, heat transport in the South Atlantic Ocean, effect of clouds in the Arctic, large scale interaction between Arctic ice area and northern hemisphere atmosphere, and ice dynamics in the Arctic.

Experiments in the Arctic (POLEX-North) were carried out in Arctic Canada during the period from November 1979 to January 1980. The main object of the experiments is to study the mechanism of variation of heat sink in the Arctic area, through the observations of clouds and precipitation. Formation of clouds and pre-

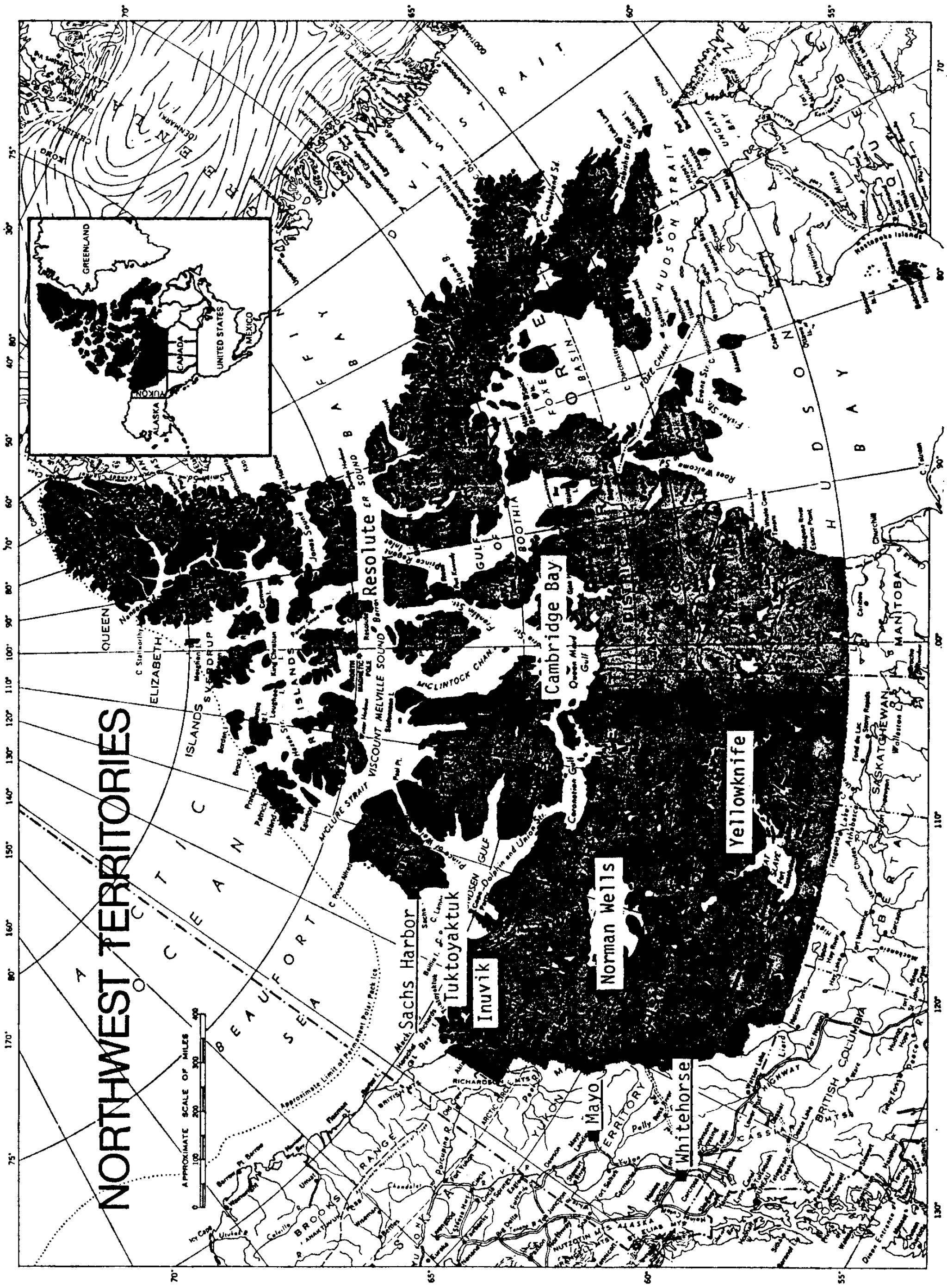


Fig. 1. Map showing the sampling stations in Northern Canada.

cipitation has a big effect on the energy exchange between the atmosphere and land surface through radiation processes, because areas of cloud cover and snow cover can change the albedo of a land surface. However, the observations of clouds and precipitation are few in the Arctic, especially in the mid-winter season. This is one reason why the experiment was planned in Arctic Canada in the winter.

The experiments were carried out in Inuvik (68°22′N, 133°42′W), Northwest Territories, near the Arctic Ocean (Fig. 1). This place was selected for the following reasons: existence of meteorological stations for upper air and ground observations, possibility to use research facilities in the town, and convenience for transportation of such big instruments as meteorological radars. Another reason is that some members joining of the expedition have had experience in observing snowfall in this area through the project "Observation of snow crystals in the Arctic Canada" by the Cloud Physics Group, Hokkaido University, 1977.

The observations were made mainly at the Inuvik Scientific Resource Centre in Inuvik Town. The observation period was from November 1979 to January 1980, but after preparation detailed observations were concentrated in the period from December 1, 1979 to January 6, 1980.

The participants in the observations in Inuvik were

Takao TAKEDA (Leader)	Water Research Institute, Nagoya University,
Katsuhiro KIKUCHI	Department of Geophysics, Faculty of Science, Hokkaido University,
Kikuo KATO	Water Research Institute, Nagoya University,
Yasushi FUJIYOSHI	Water Research Institute, Nagoya University.

The main observations and main observers were as follows:

(a) Observation of fine structure of precipitating clouds by 8.6 mm vertically pointing radar (TAKEDA and FUJIYOSHI),

(b) Observation of distribution and movement of precipitating clouds by 3.2 cm PPI radar (KIKUCHI),

(c) Observation of types and numbers of snow crystals on the ground by the use of plastic replica method, microscopes and automatic recorder (KIKUCHI),

(d) Sampling of new snow and deposited snow for the measurement of $\delta^{18}O$ and trace elements (KATO).

The observations were quite successful, since various types of snowfall occurred during the observation period when the air temperature changed from 0°C and −40°C near the ground. Preliminary results obtained from the observations and the data have been reported as "Observations of Clouds and Precipitation in the Arctic Canada", edited by HIGUCHI, TAKEDA and KIKUCHI (Organizing Committee for POLEX, Tokyo, 189 p., 1981). The present paper contains a summary of the results described in the papers in that report. The results obtained by detailed analyses will be published in the near future.

2. Characteristic Features of Wintertime Clouds and Precipitation in Arctic Canada

(T. TAKEDA, Y. FUJIYOSHI and K. KIKUCHI)

Following the observations of snow crystals performed in 1977 in Arctic Canada by the Cloud Physics Group, Hokkaido University, we made observations of clouds and precipitation in Arctic Canada from November 1979 to January 1980. The purpose of our observations was to deepen the understanding about the types and structure of wintertime clouds, the features of precipitation originating from them and the origin of precipitation water in Arctic Canada. Observations were made at Inuvik in the Northwest Territories (Fig. 1) mainly by a vertically pointing radar of 8.6 mm wave length and PPI radar of 3.2 cm in wave length, a snow-particle-measuring system, microscopic photographs of ice particles on the ground and chemical analyses of snow. Characteristic features of clouds and precipitation were

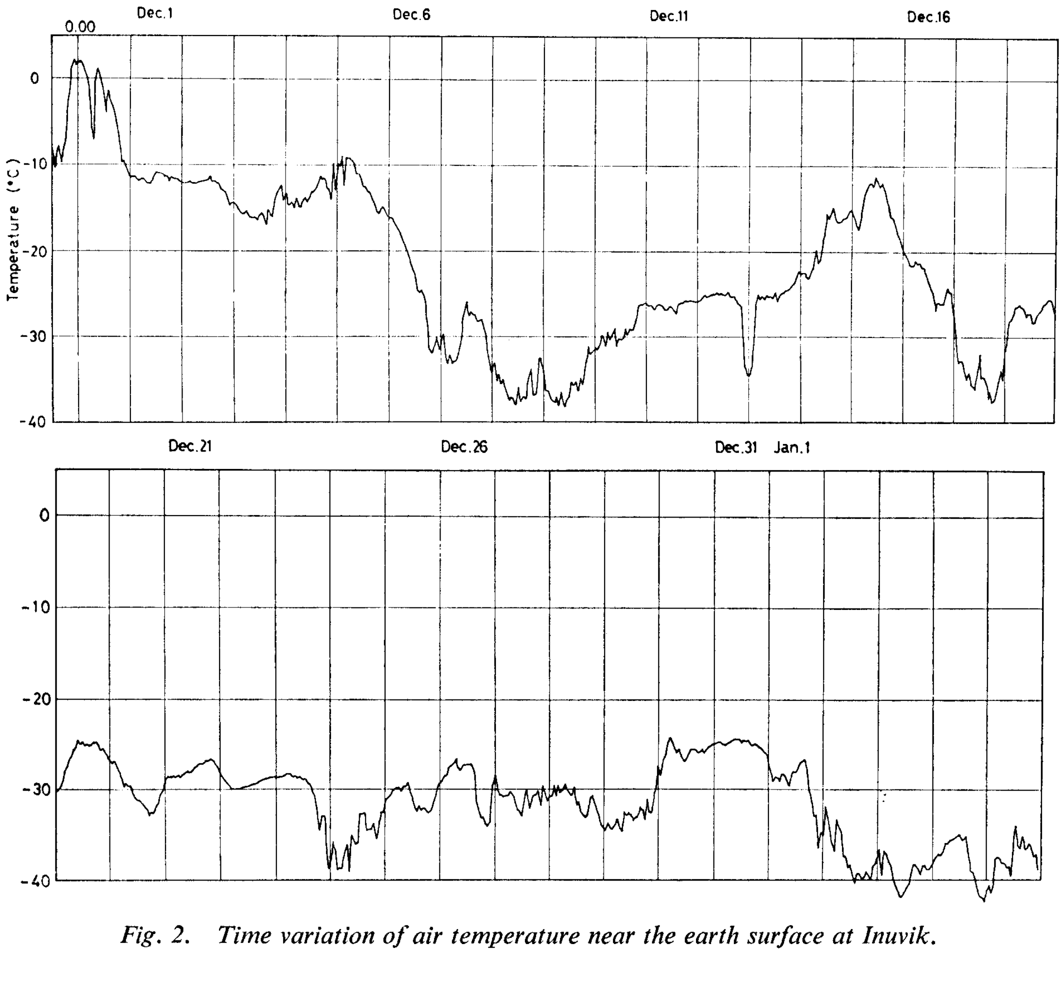


Fig. 2. Time variation of air temperature near the earth surface at Inuvik.

clarified on the basis of the data of upper-air soundings at Inuvik and our observations.

Observations were made during the period of November 16, 1979 to January 14, 1980, with the main observations being carried out from December 1, 1979 to January 5, 1980. As shown in Fig. 2, warm and cold periods alternated and the air temperature near the earth surface changed from 0°C to −40°C during the period of the main observations. Various types of clouds and precipitation were observed in various meteorological situations.

The vertical profile of temperature observed at Inuvik Upper-Air Station showed an interesting variation in accordance with the alternative appearance of warm and cold air-masses over Inuvik. Figure 3 shows three typical examples of vertical temperature profiles. The profile observed at 1700 LST on December 15 (00Z on December 16) is a typical example when a cold air-mass originating in the Arctic Ocean spread over the Northwest Territories. Although the occurence of an inversion layer or very stable layer is very frequent near the earth surface in winter in Arctic Canada, it did not occur on this date. The profile in such case will be called profile B. A very interesting profile, which had a nearly constant temperature of −25°C to −30°C below 700 mb level, occurred at 1700 LST on December 17. A low pressure centre was situated over the Gulf of Alaska and warm air spread over the Northwest Territories at middle levels under the influence of this low pressure system. It would be reasonable to say that a deep layer of nearly constant temperature was formed as a result of the intrusion of warm air originating from the Pacific Ocean at middle levels and the cooling of cold air-mass originated from the Arctic Ocean due to the heat exchange with the very cold earth surface. The atmosphere was rather calm near the earth surface in this situation, which will be called profile C.

The vertical profile of temperature observed at 1700 LST on December 20 (00Z on December 21) shows the appearance of a warm air-mass over Inuvik. It is to

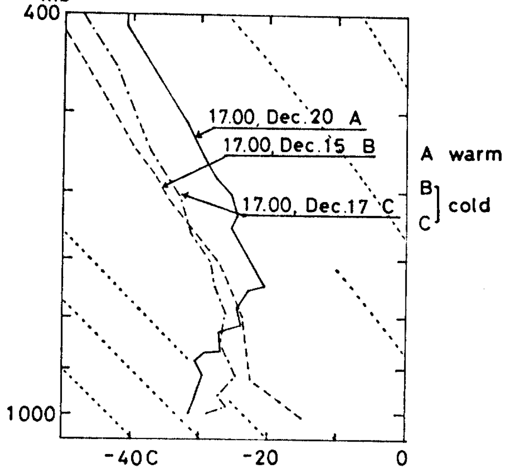


Fig. 3. Three typical examples of vertical profile of temperature over Inuvik.

be noted that there is a very intensive inversion layer at low levels. This profile would have been formed by the breaking in of warm air through almost the whole layer under the low pressure system moving from the Gulf of Alaska into the interior of the continent and by the persistent cooling of warm air near the earth surface. This case will be called profile A.

These three profiles occurred quite often during the observation period. All of the profiles observed during observation period can be classified into one of three types. Hereafter the above-mentioned profiles will be called profiles A, B and C, respectively, and periods showing these profiles will be called periods A, B and C, respectively. As known from the above description, we can say that period A was a warm period and periods B and C were cold periods.

It was possible to classify the types of clouds into three types on the basis of characteristic vertical profiles of temperature. Typical examples of them are shown in Fig. 4. A cloud layer is defined as a layer of more than 90% relative humidity with respect to water. Type I is a cloud layer where the lapse rate of temperature is nearly moist adiabatic. The temperature profile in a cloud of type I is usually seen in low and middle latitudes. In the case of type II, temperature hardly changes with height, and it increases with height in the cloud of type III. Vertical profiles of temperature in clouds of types II and III, which are rarely observed in low and middle latitudes, imply that these clouds were not formed by upcurrents. As seen in Fig. 4a, clouds of types I and III or types I and II often constituted a two-layer cloud system. Sometimes two types of vertical profiles of temperature were mixed in one cloud layer. This type of profile will be called type IV.

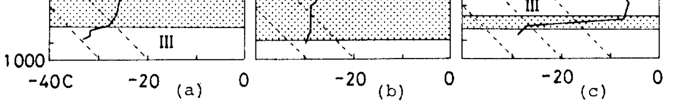


Fig. 4. Three types of vertical profiles of temperature in cloud layer which is shown by shaded area.

Table 1 shows the frequency of appearance of each type of temperature profile during the observation period, which is deduced from upper-air soundings performed every 12 hours at Inuvik.

Table 1. Frequency of different temperature profiles in cloud layer.

<table>
<tr><th colspan="2">Type of temperature profile</th><th>I (\) wet adiabatic</th><th>II (|) constant</th><th>III (/) inversion</th><th>IV mixed</th><th>Total</th></tr>
<tr><td rowspan="3">Period</td><td>A (warm) 31</td><td>10</td><td>2</td><td>13</td><td>17</td><td>42</td></tr>
<tr><td>B (cold) 9</td><td>4</td><td>5</td><td>0</td><td>1</td><td>10</td></tr>
<tr><td>C (cold) 27</td><td>0</td><td>24</td><td>1</td><td>2</td><td>27</td></tr>
</table>

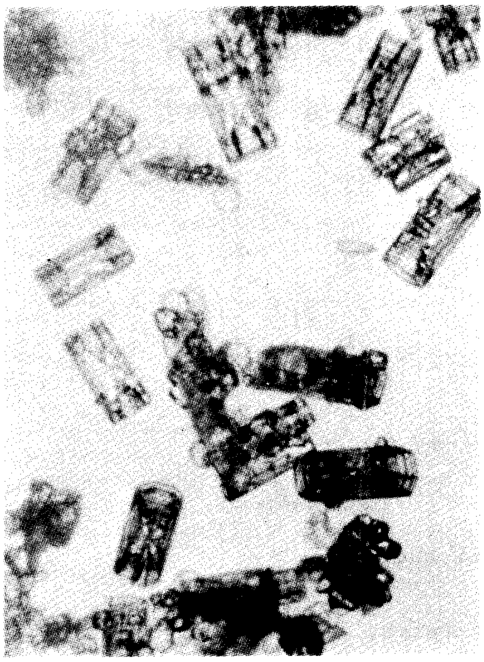
Table 2. Summary of features of each type of clouds.

<table>
<tr><th></th><th>Radar echo</th><th colspan="2">Ice particles</th></tr>
<tr><td>I (\)</td><td>Convective</td><td colspan="2">Crossed plates
Bullets
Rimed crystals</td></tr>
<tr><td>II (|)</td><td>Layer</td><td>(Diamond dusts)
Columns
Columns + (bullets or crossed plates)</td><td>Shallow cloud
↓
Deep cloud</td></tr>
<tr><td>III (/)</td><td>No</td><td colspan="2">(Diamond dusts)</td></tr>
<tr><td>IV</td><td></td><td colspan="2">"I (\)" + columns</td></tr>
</table>

Table 2 summarizes the features of radar echoes and ice particles observed in each type of cloud, which will be described in more detail in following papers of this report.

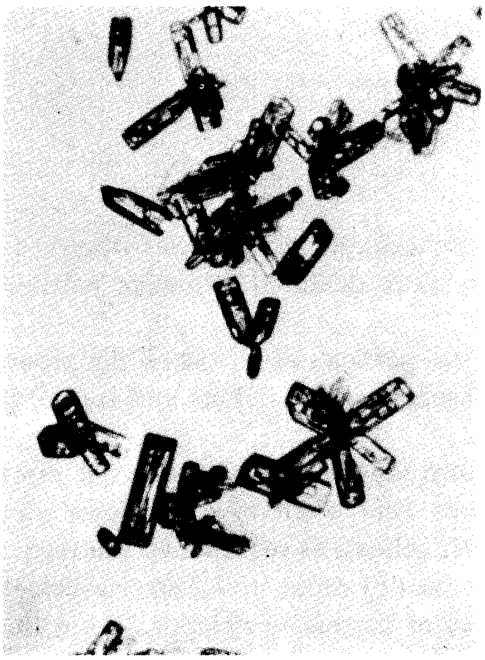
Figure 5 shows examples of predominantly ice particles observed on the ground, that is, columns, crossed plates, bullets and combinations of bullets and ice needles (or diamond dust).

Type I clouds of moist-adiabatic temperature lapse rate were observed mostly during warm period A and they were composed very often of a two-layer cloud system, together with other types of clouds. Their echoes, as revealed by the vertically pointing radar of 8.6 mm in wavelength and the PPI radar of 3.2 cm wavelength, had the features of convective cloud. The types of particles originating from these clouds changed depending upon the location relative to the centre of a travelling convective echo. Crossed plates and bullets were the main particles. Rimed crystals and graupels were sometimes observed below type I clouds. It can be said that type I clouds would have been formed in association with disturbances such as cyclones,

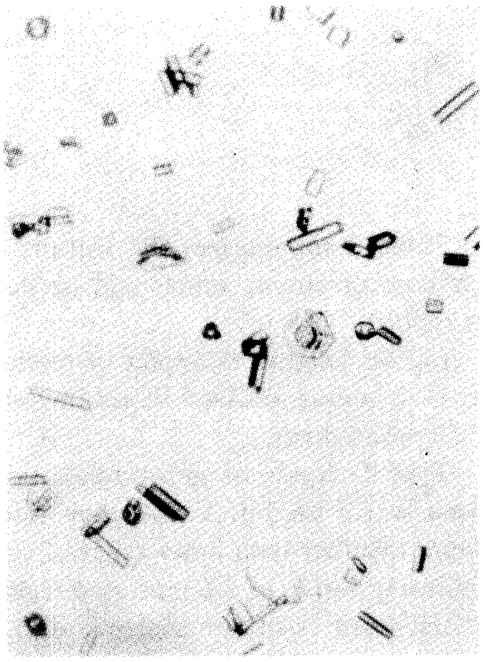


Column. 1150 on December 5. (×60)

Crossed plates. 1100 on December 12. (×50)



Bullet and conbinatin of bullets. 1620 on December 22. (×52)



Ice needle (or diamond dust). 2015 on December 29. (×60)

Fig. 5. Typical examples of snow crystals.

and they contained a large amount of super-cooled water droplets.

Most of the type II clouds were found during cold period C. Their echoes showed the features of layer clouds. However, echoes were not always uniform horizontally, and sometimes included inclined streaks. Ice particles observed in relation to these clouds tended to change with the depth of clouds. Diamond-dusts were seen in the case of very shallow clouds and columns were dominant particles below shallow clouds. In the case of deep clouds in the upper part of which temperature decreased with height in a nearly moist-adiabatic lapse rate, bullets or crossed plates were found, together with many columns. Some type II clouds were not identified clearly by eye observation, though ice particles falling from them could be detected with sufficient intensity by the 8.6 mm radar.

Most type III clouds formed in inversion layers were observed during warm period A, and they did not show any radar echo. Though diamond dusts were sometimes seen in the these clouds, these particles were not detected by the 8.6 mm radar, probably because of the formation of particles at very low levels.

Type IV clouds were found mainly during warm period A. Their upper part had the temperature lapse rate of type I clouds and their lower part showed the lapse rate seen in type II or type III clouds. Therefore, the fine structure of echoes was rather complicated. Many types of ice particles fell from these cloud systems. This can be interpreted to mean that columns were added to particles seen in type I clouds.

3. Characteristic Properties of Precipitation Particles in the Winter Season at Inuvik

(K. KIKUCHI, S. TSUBOYA, N. SATO, Y. ASUMA and T. TAKEDA)

In obtaining information on the horizontal and vertical distribution of precipitation clouds, a short-range PPI weather radar of 3.2 cm wavelength was used. A parabolic type antenna 1.2 m in diameter was set up on a flat roof of the Inuvik Scientific Resource Centre and main indicator and transmitter/receiver equipment were set up on the third floor in the same Resource Centre. The scanning time of the antenna was 15 seconds and a display of the main indicator was photographed automatically by a motor driven camera at 5 or 10 minute intervals.

Ice and snow crystal observations were carried out in a storage hut located on the premises of the Resource Centre. A polarization microscope, Formvar solution method (replica) and a snow particle measuring system (SPMS) designed for this experiment by KIKUCHI *et al.* were used for the observations of the number, flux and type of precipitation particles. A polarization microscope with double cameras was used to take photographs of the shapes of snow crystals, and to determine the principal axis of the crystals, at approximately 10 minute intervals or on random occasions; one of the cameras was for reversal film and the other was for monochrome film. Simultaneously, falling snow crystals were collected by sedimentation and replicated on 25×75 mm glass slides coated with a 0.5% Formvar solution at 5 or 10 minute intervals. The SPMS consists of a collector, controller, television monitor and video tape recorder. The collector consists mainly of a turntable receiving falling snow crystals entering from an intake and a television camera for recording the crystals.

Figure 6 shows a time-height cross section of air temperature and relative humidity from the surface up to the 400 mb level from November 29, 1979 to January 6, 1980 at Inuvik. The isotherms are drawn at intervals of 5°C. On the other hand, stripped histograms show cloud layers which are defined to be layers of more than 90% relative humidity with respect to water. Short horizontal bars with spikes at both ends above the upper rim of the figure show the observation period of snow crystals. Typical shapes of snow crystals observed during the periods were sketched by graphic symbols and additional characteristics, for instance, rimed and flake crystals based on the classification of solid precipitation agreed upon by the International Commission on Snow and Ice in 1949. As may be clearly seen, the classification does not include crossed plates (formerly side planes) type snow crystals, which are typical shapes growing in cold temperature regions. Thus we have added this shape to the classification depicted by a graphic symbol (⊖). Furthermore, the discovery and frequency of the peculiar shapes of snow crystals are the most interesting, and they are now very familiar in lower temperature regions, for instance, below −25°C; we added these shapes to the classification depicted by a graphic symbol (〈|〉). This graphic symbol indicates a tetragonal shape which is formed by two prism planes from two columns or bullets. Therefore, the diagonal line shows the grain boundary between both prism planes. Further, "seagull" shaped snow crystals reported by KIKUCHI and KAJIKAWA in the 1977 expedition at the same place are highly interesting and we added the crystals using the graphic symbol (﹀).

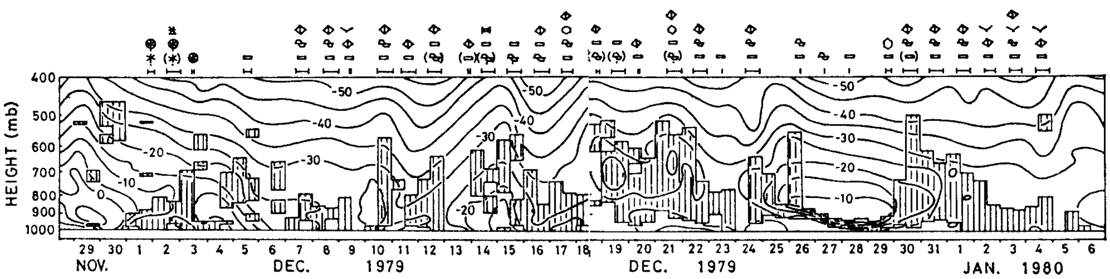


Fig. 6. Time-height cross section of air temperature and cloud layers at Inuvik.

To estimate the precipitation intensity in polar areas is highly important to understand the precipitation mechanism, properties of precipitating clouds, and the water budget in the areas. Throughout the observation period, a relationship between the maximum precipitation intensity and the temperature at cloud base ob-

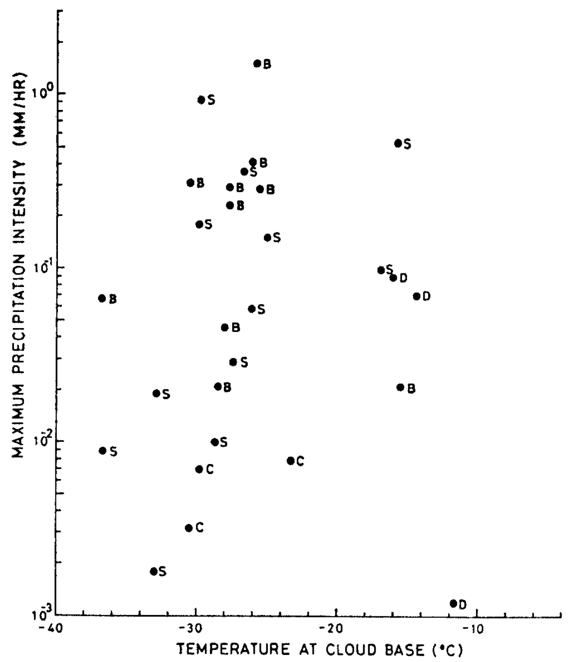


Fig. 7. Relation between the maximum precipitation intensity and temperature at cloud base to individual shapes of snow crystals (B: bullets and combinations of bullets, C: columns, D: dendrites, S: crossed plates (formerly side planes)).

tained from sounding data is shown in Fig. 7. Each black dot shows the maximum precipitation intensity in one successive snowfall. The letters B, C, D and S stand for bullet snow crystals and combinations of bullets, column, dendrite and crossed plates (formerly side planes), respectively. Although the data are widely scattered, it appears that the maximum precipitation intensities of the bullets and combinations of bullets are larger than those of other crystals. This is the reason why the combinations of bullets prevail compared to single bullets throughout the observation period.

Figure 8 shows the relation between cloud thickness, maximum and minimum temperatures in clouds, weather conditions and shapes of snow crystals. In the figure, the cloud thickness, defined as the thickness of the layer where the humidity is more than ice saturation, and range between the maximum and minimum temperature in clouds are shown with horizontal lines, with open circles at both ends. The letters B, C, D and S indicate bullet snow crystals and combinations of bullets, column, dendrite and crossed plates, respectively. Arrows drawn on the right side of each letter show the correlation between the maximum size and the number flux, namely, arrows directed to the upper right, horizontal and lower right show positive, no and negative correlations, respectively. These tendencies were classified by means of the weather charts of synoptic scale at 850 mb (A, B and C) and the vertical tem-

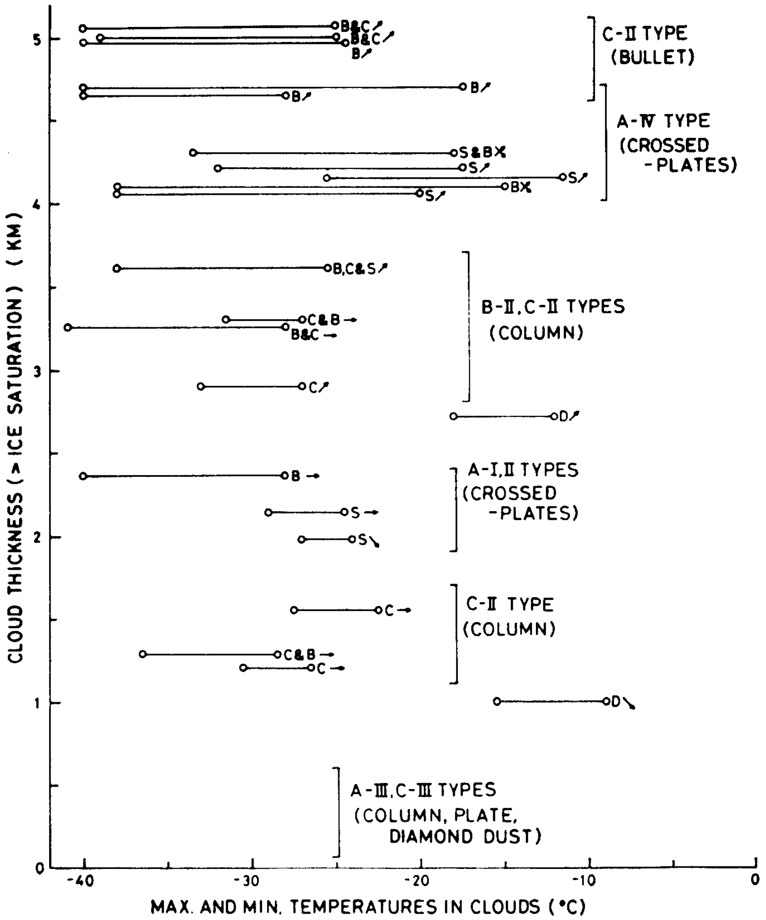


Fig. 8. Relation between cloud thickness, maximum and minimum temperatures in clouds, weather conditions of synoptic scale and shapes of snow crystals.

perature profiles in clouds by sounding data from the surface up to 400 mb (I, II, III and IV); they were classified from A-I to C-III type. These types, furthermore, were classified corresponding to the shapes of snow crystals: bullets, columns and crossed plates. Although a relation between the maximum size and number flux of diamond dust was not obtained by SPMS, it is possible to estimate a cloud thickness of a few hundred meters and a maximum temperature of approximately $-25°C$. However, dendritic crystals were not classified because there were only two cases in this observation period. As the most typical shape of snow crystals in the mid-winter season in cold temperature regions are bullets, columns and crossed plates, it is thought that Fig. 8 sufficiently expresses the dominance of these crystal shapes.

As the temperature condition throughout the observation period, on the average, was approximately 5°C lower than the 1977 observation, a number of peculiar shapes of snow crystals such as "Gohei" and "Seagull" were observed. When the warm air from the Pacific Ocean was advected over the observation station, however, dendritic crystals were observed as rimed and snowflakes, and at times, graupel particles. Accompanying these snow crystals, a PPI weather radar showed convective type echoes. The maximum precipitation intensities in a successive snowfall during the observation period were on the order of 10^{-3} to 10^{0} mm/hour. The maximum precipitation intensity of bullet type crystals was more than those of other shapes. Converting the number fluxes into masses using the maximum precipitation intensity, they fell into the range between 1×10^{-3} mg and 1×10^{-2} mg. The equivalent diameters corresponding to these masses were from 0.12 mm to 0.27 mm. When the cloud thickness was large, the maximum size increased with the increase in number flux, but when the cloud thickness was very thin the maximum size decreased with the increase in number flux. On the basis of the above-described relation, a correlation between cloud thickness, maximum and minimum temperatures in clouds, weather conditions and the shapes of snow crystals was found; it is shown in Fig. 8.

4. Radar Observations of Wintertime Snow Clouds in Arctic Canada

(Y. Fujiyoshi, T. Takeda and K. Kikuchi)

In cold regions, many investigators observe ice crystals on the ground in order to clarify the formation and growth mechanisms of ice crystals. However, it is difficult to determine cloud layers where ice crystals are formed and grow, except from upper air sounding data, since almost all the layers could be saturated with respect to ice in most cases. We observed the radar echo structures of snow clouds including "clear sky precipitation" and snow crystals from them on the ground simultaneously to study the mechanisms of precipitation formation in Arctic Canada in the winter.

We used a vertically pointing radar (V-radar) of 8.6 mm wavelength to study the fine structure of snow clouds, and we also used a PPI radar of 3.2 cm wavelength to study their horizontal scale and movement. The characteristics of the two radars are shown in Table 3.

Even when the air temperature is quite low, ice crystals are not necessarily formed in the water saturation layer. Some differences can be expected between the levels of the cloud top and the echo top. We define the level of the cloud top (H_{cl}) for a cloud layer where relative humidity with respect to water is more than 90% and the level of the echo top (H_{ec}) for the echo layer detected by 8.6 mm V-radar. When two or three tops can be defined, the highest one is selected here as the cloud top and the echo top.

In Fig. 9 we compared H_{cl} obtained from sounding data at 0500(12Z) and 1700 LST(00Z) with H_{ec} determined from radar data obtained from 0000 to 1200 LST and from 1200 to 2400 LST, respectively. Letters A, B and C in Fig. 9 cor-

Table 3. Characteristics of radars.

	Vertically pointing radar	Short-range PPI radar
Transmitting frequency (wave-length)	34860±261.45 MHz (8.6 mm)	9375±30 MHz (3.2 cm)
Peak transmitting power	30 kW	20 kW
Pulse width	0.5 μs	1.0 μs
Pulse repetition frequency	500 pulses/s	700 pulses/s
Beam width	0.7°	1.8°
Antenna	Parabolic-type	Parabolic-type
	900 mm (diameter)	1200 mm (diameter)
Minimum dectectable power	−90 dBm	
Minimum detection range	100 m	

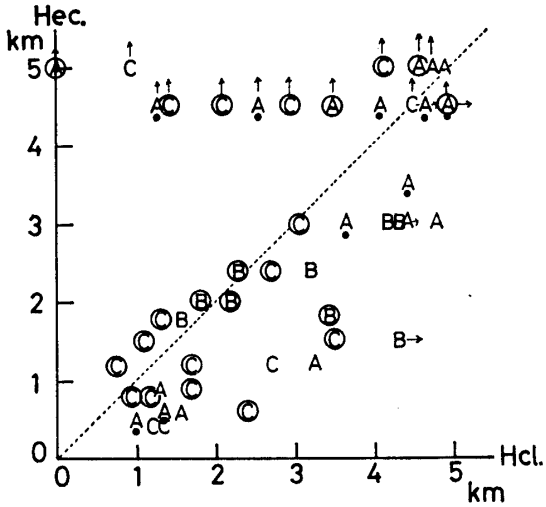


Fig. 9. Difference between the levels of cloud top (H_{cl}) and echo top (H_{ec}). Letters A, B and C correspond to periods A, B and C, respectively. Vertical and horizontal arrows indicate that H_{ec} and H_{cl} might be underestimated because of the limitation of radar and sounding systems, respectively. Letters with dots and encircled letters mean that rimed crystals and snow crystals of peculiar shape were observed, respectively.

respond to the periods A, B and C which were defined in Section 2. Vertical and horizontal arrows indicate the case in which H_{ec} and H_{cl} might be underestimated because of the limitation of radar and sounding systems. According to Fig. 9, the cases can be separated into two groups. In the first group, the level of the echo top was nearly the same as or lower than the level of the cloud top. In the second group, H_{ec} was always higher than 4500 m independent of H_{cl}, but the atmosphere was saturated with respect to ice at least above 4500 m. The existence of the second group indicates that the formation of ice crystals can occur in an ice saturation layer, at least above 4500 m, without the existence of water saturation clouds. It is interesting that such cases were observed in periods A and C, but not in period B.

Typical shapes of snow crystals during the observation period were bullets, columns and crossed plates; though only dendrite type crystals fell from December

1 to December 3. In periods A, B and C shown in Fig. 3, the dominant type of crystal changed with time in many cases. In period A there were cases in which only crossed-plate type crystals were observed for a few hours. In period C there were cases in which only bullet or column type crystals were observed for a few hours. However, in period B there was no case in which only one type of crystal was observed for a few hours.

In period C with constant temperature layer C, column type crystals were predominantly observed. But bullet and/or crossed plates type crystals were often observed together with column type crystals in accordance with the change in the level of the echo top, the depth of the echo layer and the radar echo structure. When a horizontally uniform radar echo appeared in the nearly isothermal layer and the air temperature in the cloud layer was between -20 and -25°C, column type crystals fell predominantly. However, when the centre of the streak-like radar echo passed over the radar site, crossed-plate type crystals were observed together with column type crystals, and both the number flux and maximum size of crystals were large. When a cloud layer existed in the nearly isothermal layer of -25 to -30°C and a layer-echo appeared, column, bullet and crossed-plate types of crystals were observed in nearly the same concentration. When the echo top was just above the isothermal layer and an intensive streak-like radar echo appeared, both bullet- and column-type crystals were predominant. When the radar echo was intensive and crossed-plate type crystals were predominant, the radar echo was weak; ice particles would have been formed and grown in the layer with air temperature of -25 to -30°C. When the echo top was higher than 4500 m and an intensive streak-like radar echo appeared, bullet-type crystals fell predominantly, which suggested that they were formed and grew in the layer with air temperature lower than -30°C.

A strong inversion appeared in period A. Clouds observed in the inversion layer rarely showed a radar echo, and ice fog was often observed. Bullet and column type crystals were observed, when a layer-echo appeared in the inversion layer and ice particles could be formed and grow only in the layer colder than -30°C. When the echo top was higher than the inversion layer, streak-like radar echoes appeared. In this case, bullet and column type crystals were predominantly observed; at such a time it can be considered from radar observations that ice crystals are formed and grow only in the layer colder than -30°C. Crossed-plate type crystals were predominantly observed, when ice particles can be considered to be formed and grow only in the layer of about -20°C. When quite intensive streak-like radar echoes appeared above the inversion layer, heavily rimed crystals were observed. It is inferred from observations of radar echo and snow crystals in such cases that heavily rimed crossed-plate type crystals were formed and grew in or near the centres of updraughts.

In period B, with an inversion or very stable layer, a horizontally rather uniform radar echo often appeared. Bullet and column type crystals were predominantly observed as well as in periods A and C, when radar observations suggested that ice particles were formed and grew in the layer with air temperature around $-30°C$. But, period B is different from the period A; for example, air temperature in the upper part of the cloud layer was always colder than its lower part in period B. This difference sometimes caused the relationship between echo intensity and types of snow crystals which is apparently different from that of period A.

5. Oxygen Isotopic Composition of Surface Snow in Arctic Canada

(K. KATO and K. HIGUCHI)

No systematic study has been done on the isotopic composition of surface snow in the Arctic and sub-Arctic. To investigate the process of formation of snow and the transportation process of transport of water vapor to Northern Canada, sampling of surface snow in Northern Canada was done to determine the oxygen isotopic composition. The samples are as follows:

1) Snow sampled at different dates at Inuvik (shown in Fig. 1),

2) Accumulated snow sampled at various stations in Northern Canada (shown in Fig. 1).

The analytical results are given in $\delta^{18}O$ notation as follows,

$$\delta^{18}O = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}} \times 1000 \ (‰)$$

SMOW: Standard Mean Ocean Water

and the analytical error is $\pm 0.2‰$.

Figure 10 shows the variations of $\delta^{18}O$ of snow and meteorological conditions

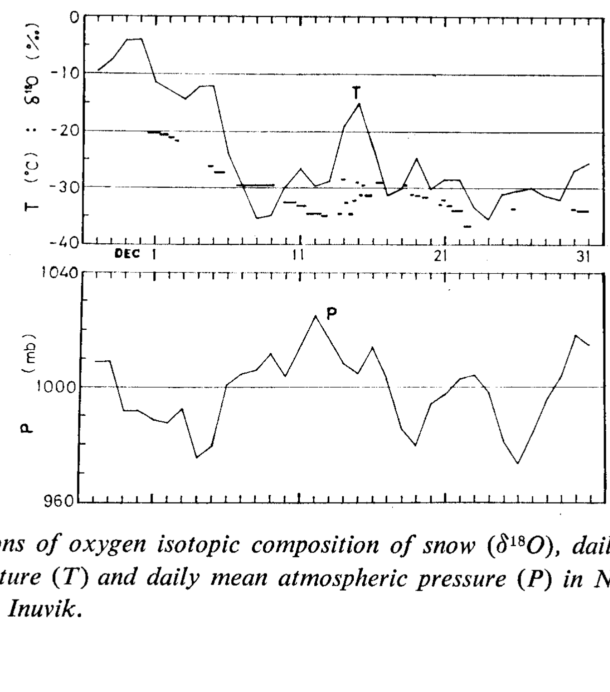


Fig. 10. Variations of oxygen isotopic composition of snow ($\delta^{18}O$), daily mean surface air temperature (T) and daily mean atmospheric pressure (P) in November–December 1979, at Inuvik.

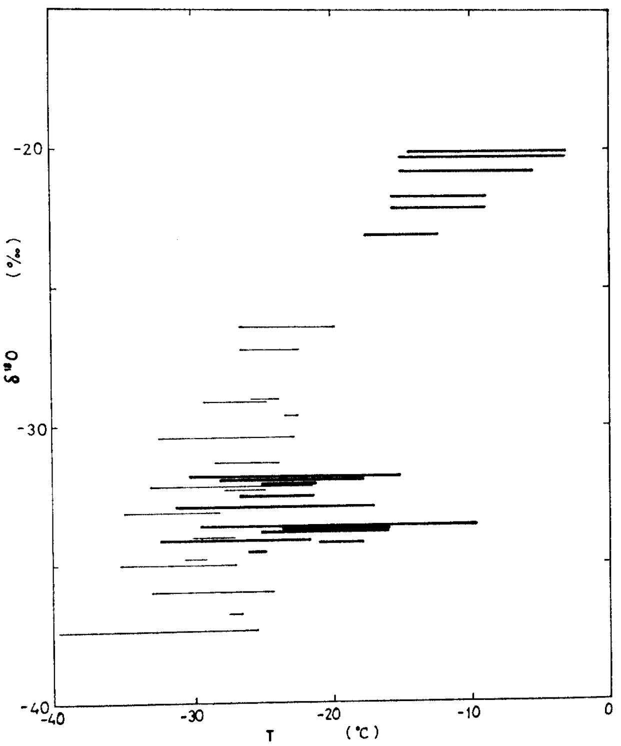


Fig. 11. Oxygen isotopic composition of snow ($\delta^{18}O$) at Inuvik with respect to the temperature range in the corresponding cloud layer (T). The bold line shows rimed crystals.

in November–December 1979. The variation of $\delta^{18}O$ of snow follows fairly faithfully that of daily mean surface air temperature: the $\delta^{18}O$ of snow fairly increases and decreases with increasing and decreasing temperature, respectively. It is rather clear in Fig. 10 that $\delta^{18}O$ of the snow increases and decreases with decreasing and increasing pressure, respectively.

Figure 11 shows $\delta^{18}O$ of snow with respect to the temperature range in the corresponding cloud layer (temperature of formation of snow), which is determined as a layer with relative humidity of more than 90% from the aerological data. The bold line shows rimed crystals. They are formed in warm and wet air supplied by cyclones passing from the Northeast Pacific Ocean. Almost all of the others are formed in cold air supplied from the Arctic Ocean. It can be seen in Fig. 11 that $\delta^{18}O$ of unrimed snow formed in the cold Arctic air is higher than that of rimed crystals formed in the warm and wet Pacific air, even at the same temperature of formation. This is an interesting and rather unexpected result. This suggests that $\delta^{18}O$ of water vapour originating from the Arctic Ocean is higher than that from the Northeast Pacific Ocean, and that the transportation process of water vapor under an anticyclone differs from that under a cyclone.

It can be seen from Fig. 11 that dependency of $\delta^{18}O$ on the temperature range of cloud layer for rimed crystals is different from that for unrimed crystals. This indicates that the formation process of snow in warm and wet air supplied by cyclone passing from the Northeast Pacific Ocean is different from that in cold air supplied from the Arctic Ocean.

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Appendix

Observations of Clouds and Precipitation in the Arctic Canada, ed. by K. HIGUCHI, T. TAKEDA and K. KIKUCHI, Tokyo, Organizing Committee for POLEX, 189 p., 1981.

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